WARNER

Adhesion of Cement Mortars

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ADHESION OF CEMENT MORTARS

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JAMES MADISON WARNER

ENTITLED ADHESION OF CEMENT MORTARS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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THE ADHESION OF CEMENT MORTARS.

INTRODUCTION.

Masonry is generally designed to take only compressive stresses, although it often happens that due to wind, temperature, or eccentric loading, flexural and tensile stresses are produced. Due to these strains the efficiency of many masonry structures is dependent upon the adhesive qualities of the mortar, and for this reason it is essential that the most effective mixtures be used.

The following pages contain a resumé of the tests already reported along this line together with data from tests conducted by the writer during the present year.

METHOD OF CONDUCTING THE TESTS.

The adhesive specimens were molded into the form of the standard tensile briquette and in each case a tensile test was made under exactly the same conditions as the adhesive test, with the object of discovering, if possible, what laws exist in relation to the relative strength of the former in terms of the latter. In making the adhesive tests uniform methods were followed throughout. In each case a sawn adhesive block of Bedford Limestone having a cross-section one inch square and a thickness of one fourth inch was used. These blocks were immersed in water before being used. They were inserted transversely at the center of a standard briquette mold then the ends of the latter were filled with the mortar to be tested thus forming two joints between the mortar and the block. The position of the block is shown in Fig. 1.

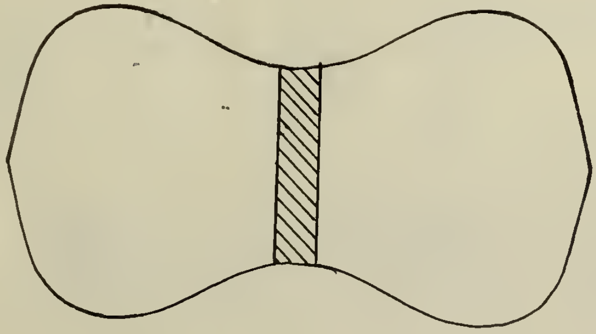

Fig. 1 Position of the Adhesion Block.

The cements used were Chicago A.A. Portland and Clark's Utica natural cement.

The sand used was Ottawa white sand which had passed a 20 mesh sieve and was retained on a 30 mesh sieve.

The Riehlé Testing Machine, a photo of which appears below, was used except in case of the weaker specimens where the more delicate Fairbanks Machine was found necessary.

TESTS.

Effect of Age and Variation in the Proportions.

Four mortars, each containing different proportions of sand, were tested for cohesive and adhesive strength, at three different ages. Table 1 shows the results of these tests and the values are shown graphically by the curves on Plate I.

TABLE 1.

Effect of Age and Variation in the Proportions.

Portland Cement Mortars.

% Water	22%		13.3%		10.9%		9.7%	
Proportions	1 : 0		1 : 1		1 : 2		1 : 3	
Ages	Ad.	Co.	Ad.	Co.	Ad.	Co.	Ad.	Co.
7 day tests	310	690	210	530	110	275	38	233
	295	910	275	600	110	300	36	215
	350	925	280	605	90	310	36	252
	355	640	205	540	105	285	40	229
	330	880	150	580	87	330		343
Average	328	809	224	571	100	300	37.5	234
28 day tests	390	825	320	750	150	390	76	306
	340	800	290	620	165	440	84	310
	365	880	250	760	170	430	66	275
	425	980	340	580	115	400	62	285
	390	925	260	635	120	430		320
Average	382	882	292	689	144	412	72	299
56 day tests	355	865	365	810	190	550	75	370
	440	840	280	720	150	565	65	345
	415	895	300	890	120	470	82	323
	400	1015	290	710	130	545	47	380
	385	880	310	715	185	430		390
Average	399	899	309	769	155	512	69.8	362

From the preceeding results it will be seen that the cohesive, as well as the adhesive, strength varies inversely with the amount of sand in the mortar and directly with the age of the briquettes. It will be noted that the neat cement mortars gave the highest strength both in adhesion and in cohesion. Attention is called to this fact here because some of the results stated later show greater strength for other proportions. Table 2, computed from the above results, gives the ratio of the adhesive to the cohesive strength, for different mortars at different ages. These values are shown graphically on Plate II.

TABLE 2.

Ratio of the Adhesive to the Cohesive Strength.

Portland Cement Mortars.

Proportions	1 : 0	1 : 1	1 : 2	1 : 3
7 days	.406	.434	.333	.160
28 days	.441	.425	.348	.241
56 days	.444	.405	.303	.193

Mortars containing up to 50% of sand have adhesive strengths approximately equal to 2/5 of the cohesive strengths. The ratio rapidly decreases as the percentage of sand is increased, the adhesive strength of a 1 : 2 mortar being only

1/3, and of a 1 : 3 mortar about 1/5 of the cohesive strength.

Table 3 shows the results of a series of tests conducted by Mr. L. C. Sabin,* in substantially the same manner as those described in the preceding paragraphs. He shows the mortars tested at six months to have the greatest adhesive strength when mixed in the proportions 1 : 1/2 and the greatest cohesive strength when mixed in the proportion 1 : 1.

TABLE 3.

Effect of Age and Variation in Proportion.

Proportions:		1 : 0		1 : ½		1 : 1		1 : 2 .	
Cement	Age	Ad.	Co.	Ad.	Co.	Ad.	Co.	Ad.	Co.
Port.	28 d.	370	386	333	710	221	747	69	167
"	6 m.	335	331	346	787	287	816	109	551
Nat.	28 d.	94	183	104	198	116	218	66	186
"	6 m.	228	263	222	334	233	383	171	376

– Sabin.

With the natural cement the 1 : 1 mortar gives the highest strength both in adhesion and cohesion when tested at 28 days as well as 6 months. These results are shown graphically on Plate III. The relation of the adhesive to the cohesive strength, computed from the above, is given in Table 4 and shown graphically by the curves on Plate IV.

*Sabin's Cement and Concrete, P. 275.

TABLE 4.

Ratio of the Adhesive to the Cohesive Strength.

Proportions		1 : 0	1 : ½	1 : 1	1 : 2
Portland	28 days	.394	.328	.295	.362
"	6 mo.	.530	.440	.351	.380
Natural	28 days	.514	.526	.533	.355
"	6 mo.	.867	.660	.609	.455

For the Portland cement, the highest value is given by the neat mixture, thus agreeing with the results of Table 2, while with the natural cement there appears to be no uniform variation, - at 28 days a 1 : 1 mixture gives the greatest value while at 6 months the highest results are given by a neat mixture. Table 5 shows the results of tests upon Portland cement mortars, conducted by Mr. Candlot and quoted by Messrs. Taylor and Thompson.* These results, however, are so irregular that little can be gained from them save that in general the adhesive strength of a 1 : 3 mortar increases more rapidly than that of a 1 : 2 mortar between the ages of 7 and 28 days.

TABLE 5.

Adhesive Strength of Portland Cement Mortars.

Cement	A		B		C		D	
Proportions	1 : 2	1 : 3	1 : 2	1 : 3	1 : 2	1 : 3	1 : 2	1 : 3
% water	15	13.8	15	12	17	15	13	12
7 days	143	143	41	33	41	37	78	60
28 days	169	209	111	77	76	96	86	125

*Taylor & Thompson's Concrete, Plain & Reinforced, P 124.

Mr. E. S. Wheeler* concluded from a series of tests, using sawn limestone adhesion blocks, that the adhesive strength of Portland cement mortar in proportions from 1 : 0 to 1 : 2 to be about 1/3 of the cohesive strength of the mortar. This value agrees closely with the results secured by the writer for a 1 : 1 mixture but is rather low for mortars containing a smaller percentage of sand.

The results of some 12,000 tests performed by Mr. Mann, and quoted by Prof. Baker,[1] show that Portland cement having a cohesive strength of 425 pounds per square inch, has but 60 to 80 pounds adhesion to limestone and that the ratio of the adhesive strength to the cohesive strength varies from 1/5 to 1/9. These experiments were made in 1882 and agree closely with other tests made about the same time but are rather low as compared with more recent tests.

The Effect of Consistency and Variation in Proportion of Sand.

Mortars containing different proportions of sand as well as different percentages of water were tested at the age of 28 days. Table 6 gives the results of these tests and the values are shown graphically on Plate V.

*Taylor & Thompson's - Concrete, Plain & Reinforced, p. 124.
[1] Baker's - Treatise on Masonry Construction, p. 95.

TABLE 6

Effect of Consistency and Variation in Proportion of Sand.

Proportions	1 : 0		1 : 1		1 : 2		1 : 3	
% Water	21%		13%		10.7%		9.5%	
Kind of Test	Ad.	Co.	Ad.	Co.	Ad.	Co.	Ad.	Co.
Portland	212	650	225	690	115	435	53	250
28 days	194	765	240	768		405	62	245
Dry	130	770	270	635	110	380	70	248
	115	620	247	600	100	330	40	252
		840	270	655	85	270		200
Average	162.7	729	250.4	669.6	102.5	364	56.2	239
% Water	22%		13.3%		10.9%		9.7%	
Portland	390	705	320	740	150	390	76	306
28 days	340	850	290	715	165	440	84	310
Plastic	365	845	250	680	170	430	66	275
	422	795	340	650	115	400	62	285
	390	820	260	780	120	430		320
Average	382	803	292	713	144	412	72	299
% Water	25%		14.3%		11.6%		10.2%	
Portland	385	860	310	670	230	470	101	362
28 days	355	750	400	885	190	510	90	368
Wet	395	885	385	765	190	480	65	305
	390	855	260	660	160	540	70	344
	425	740	355	800	130	510	55	341
Average	385	818	338	756	180	502	77	344

These results show that the effect of variations in the consistency is greater on the adhesive than on the cohesive strength and that the best results in adhesion are given by a mortar that contains considerably more water than is required for standard plasticity. Table 7 shows the ratio of

the adhesive to the cohesive strength and it will be noted that with one exception the wet mortars give the highest values. A graphical representation is shown on Plate VI.

TABLE 7.

Ratio of Adhesive to Cohesive Strength.

Portland Cement Mortar.

Proportions	1 : 0	1 : 1	1 : 2	1 : 3
Dry	.222	.324	.280	.234
Plastic	.441	.425	.350	.241
Wet	.472	.446	.359	.224

The results of a series of tests conducted upon natural cement mortars are shown in Table 8 and graphically on Plate VII. On account of the large variation and low average strengths of some of the briquettes, correct values were difficult to obtain, which fact may explain the seeming irregularities in the results. In general, the results show, as did those of the Portland cement mortars, that greater adhesive strength can be secured with wet mixtures than with dry ones.

TABLE 8.

Effect of Consistency and Variation in Proportion of Sand.

Natural Cement Mortars.

Proportions	1 : 0		1 : 1		1 : 2	
% Water	34%		17.3%		13.6%	
Kind of Test	Ad.	Co.	Ad.	Co.	Ad.	Co.
Natural 28 days Dry	95	215	42	202	40	180
	78	240	72	134	35	155
	185	260	38	160	40	184
	170	243		205	25	191
		241		185		145
Average	132	240	51	177	35	171
% Water	36%		18%		14%	
Natural 28 days Plastic	100	240	40	190	48	237
	174	280	30	165	52	215
	163	278	81	225	25	192
	130	255	56	235	44	215
		262		165	47	210
Average	142	263	52	196	44	214
% Water	38%		18.7%		14.7%	
Natural 28 days Wet	122	230	124	298	55	192
	125	237	110	240	47	210
	75	238	120	282	63	185
	140	265	112	320		212
	130	204	92	305		216
Average	118	235	112	249	55	303

The ratio of the adhesive to the cohesive strength is given in Table 9 and shown graphically on Plate VIII.

TABLE 9.

Ratio of Adhesive to Cohesive Strength.

Natural Cement Mortars.

Proportions	1 : 0	1 : 1	1 : 2
Dry	.550	.228	.204
Plastic	.541	.265	.210
Wet	.502	.450	.181

Table 10 gives the results of tests conducted by Mr. L. C. Sabin* to show the relative effects of the consistency of 1 : 1 mortars on the adhesive and cohesive strength.

TABLE 10.

Effect of Variation in Consistency 1 : 1 Mortars.

Consistency	Trifle dry		Trifle moist		Quite moist		Very moist	
Test	Ad.	Co.	Ad.	Co.	Ad.	Co.	Ad.	Co.
Port. 28 days	148	541	160	502	145	443	136	372
" 6 mo.	191	697	209	660	228	616	192	539
Nat. 28 days	96	239	96	212	87	151	70	112
" 6 mo.	146	397	165	385	164	314	126	285

\- Sabin.

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*Sabin's Cement & Concrete, p. 274.

The method of stating the amount of water used in the mortars makes any conclusions which may be arrived at from these results rather indefinite. The "Trifle Moist" mortar, however, appears in general to give the highest results. The value of the ratio of the adhesive to the cohesive strength given in Table 11 increases from the "Trifle Dry" to the "Very Moist" mixtures for briquettes tested at the age of 28 days. At the age of 6 months, however, the "Quite Moist" mortars give the largest ratio.

TABLE 11.

Ratio of Adhesive to Cohesive Strength.

Varying Consistency.

Consistency of Mortar		Trifle dry	Trifle moist	Quite moist	Very moist
Portland	28 days	.274	.318	.328	.354
"	6 mos.	.274	.312	.370	.356
Natural	28 days	.402	.452	.575	.625
"	6 mos.	.378	.430	.522	.442

– Sabin.

The Effect of the Fineness of the Cement on the Adhesive and Cohesive Strength.

Three mortars, one made entirely from cement passing a 200 mesh sieve, one from cement of standard proportions as received from the mill, and the third from cement containing a greater proportion of coarse material, were tested for adhesive and cohesive strength. The sieve analyses of the cements used are shown in Table 12.

TABLE 12.

Sieve Analyses of Cements.

Cement	% retained on 200 sieve	% retained on pan
A	0	100
B	22.4	77.6
C	44.8	55.2

It will be noted that the mixtures are such that the percentages of coarse material increases and that of the fine material decreases uniformly. Briquettes were tested at the age of 7 days. The results are given in Table 13 and the averages are represented graphically in Plate IX. These results show

TABLE 13.

Effect of Fineness of Cement on Adhesive and Cohesive Strength.

Cement	A		B		C	
Test	Ad.	Co.	Ad.	Co.	Ad.	Co.
Portland	450	640	310	690	300	675
	400	730	350	910	345	720
7 days	455	760	355	925	270	680
	300	635	330	640	290	750
	480	690	295	880		775
Average	417	671	328	809	301	720

that the fineness of the cement bears a direct relation to the adhesive strength, i.e. the finer the cement the greater the adhesive strength. The greatest cohesive strength is given by a cement of standard proportions. The ratio of the adhesive to the cohesive strength is given in Table 14.

TABLE 14.

Ratio of Adhesive to Cohesive Strength.

Cement	Ratio
A	0.621
B	0.406
C	0.418

Several briquettes were made from the material retained on the 200 mesh sieve. These specimens showed very little strength, as they broke while being placed in the testing machine, thus demonstrating that the part of the cement not passing a two hundred mesh sieve is of little or no cementing value.

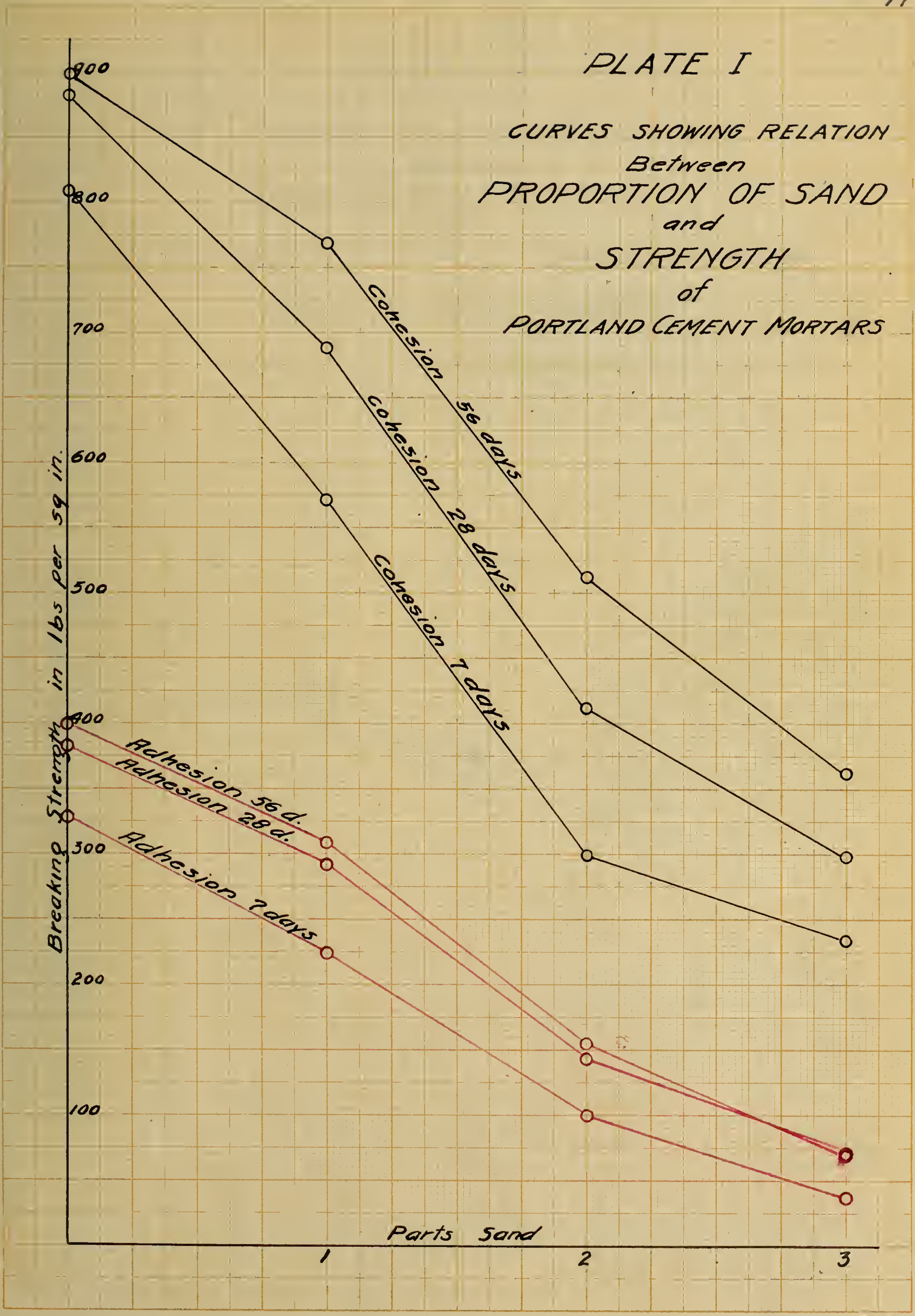


PLATE I

CURVES SHOWING RELATION
Between
PROPORTION OF SAND
and
STRENGTH
of
PORTLAND CEMENT MORTARS

PLATE II

CURVES SHOWING RELATION
Between
PROPORTION of SAND
and
RATIO of ADHESIVE to COHESIVE STRENGTH
of
PORTLAND CEMENT MORTARS

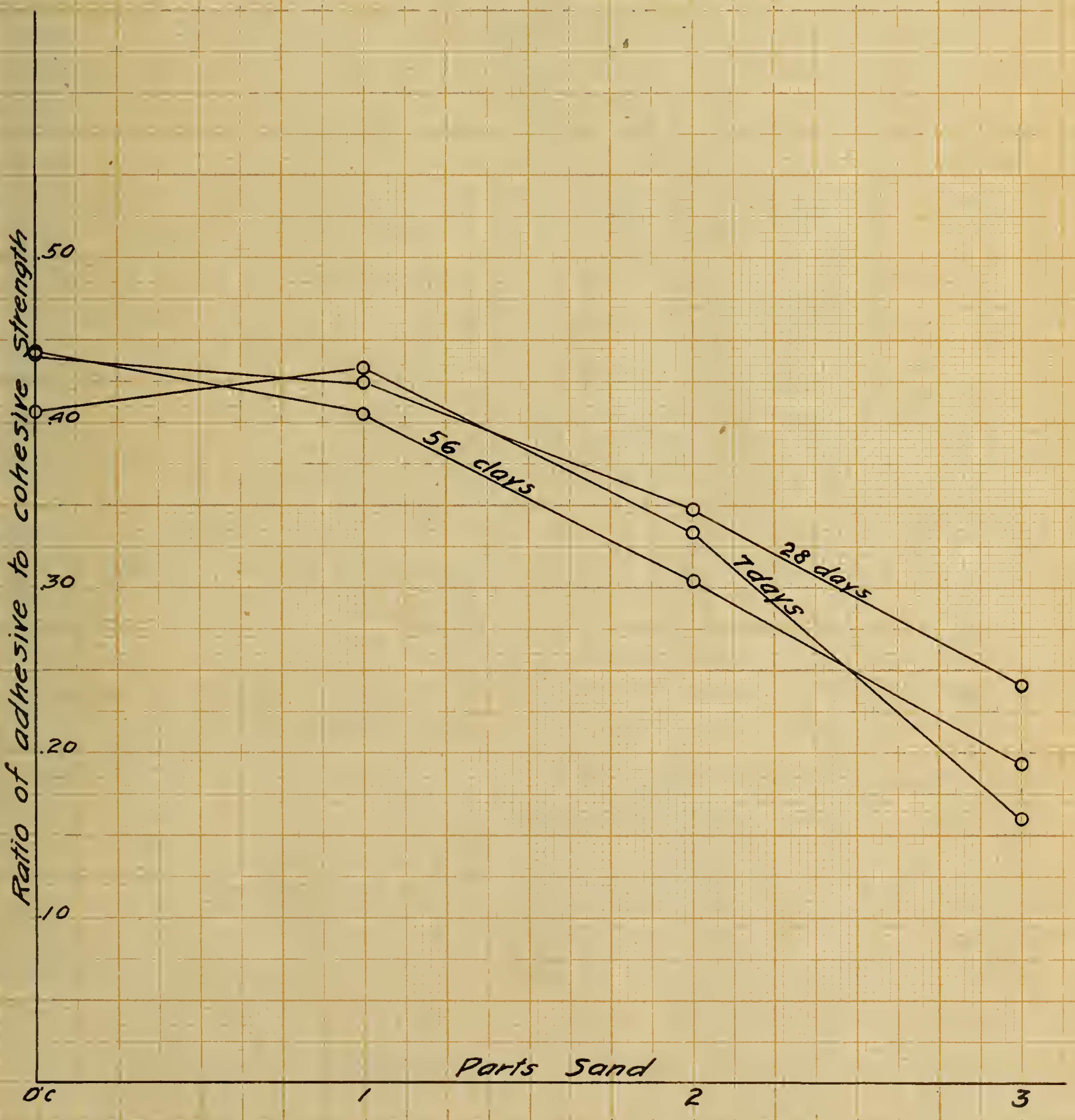
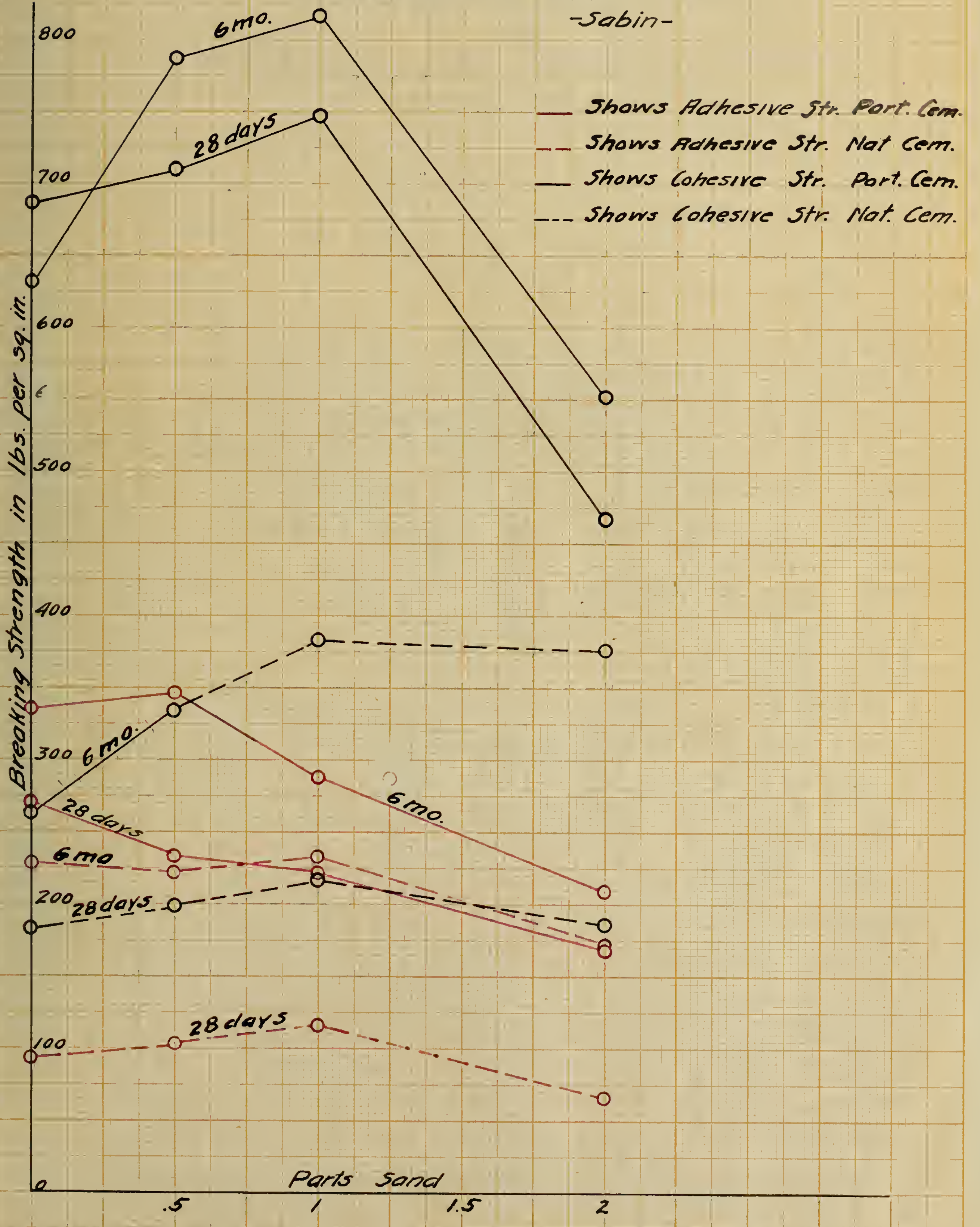


PLATE III

CURVES SHOWING RELATION
Between
PROPORTION of SAND and STRENGTH
OF CEMENT MORTARS

-Sabin-



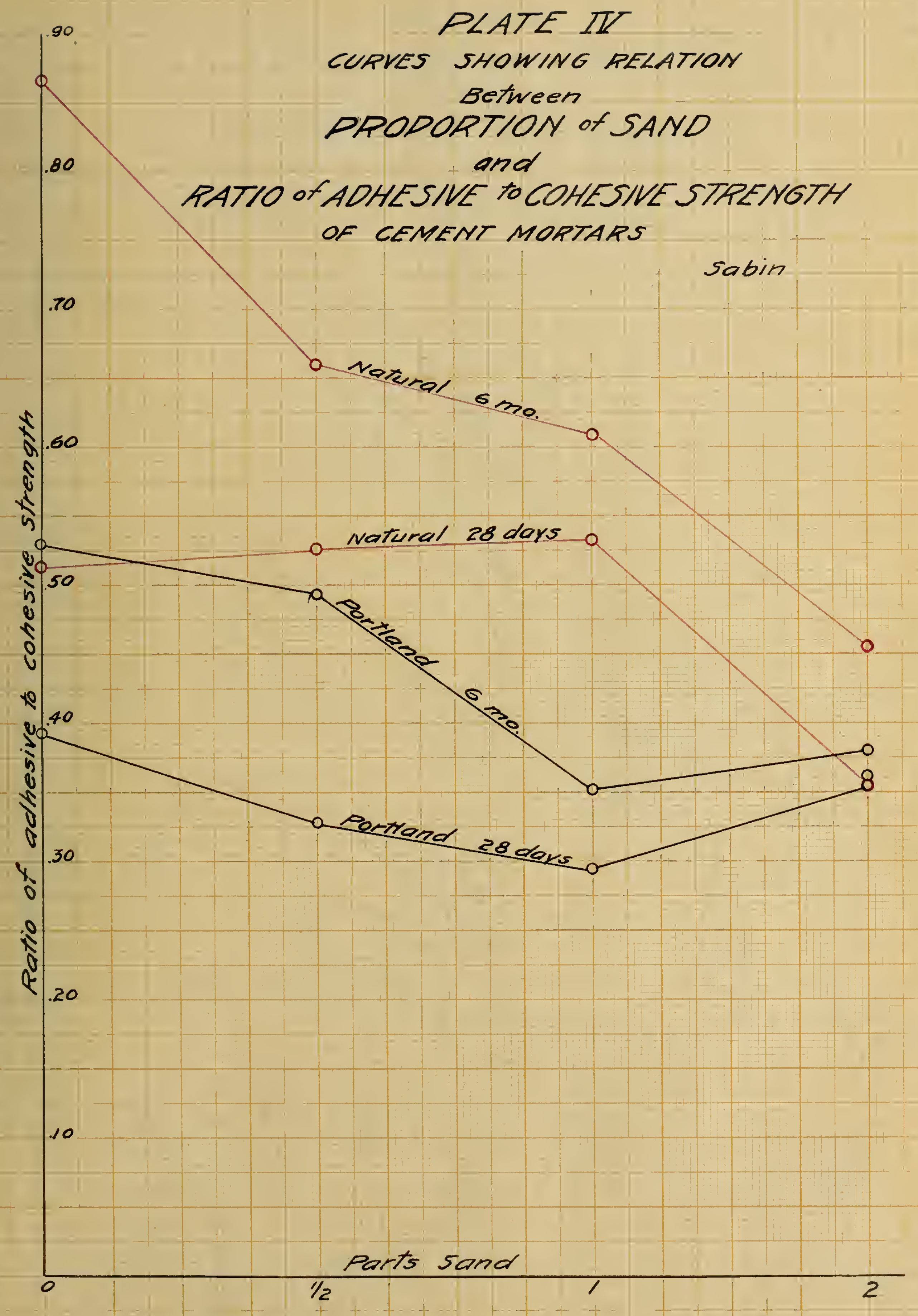


PLATE IV

CURVES SHOWING RELATION
Between
PROPORTION of SAND
and
RATIO of ADHESIVE to COHESIVE STRENGTH
OF CEMENT MORTARS

Sabin

PLATE V

CURVES SHOWING RELATION Between CONSISTENCY and STRENGTH OF PORTLAND CEMENT MORTARS

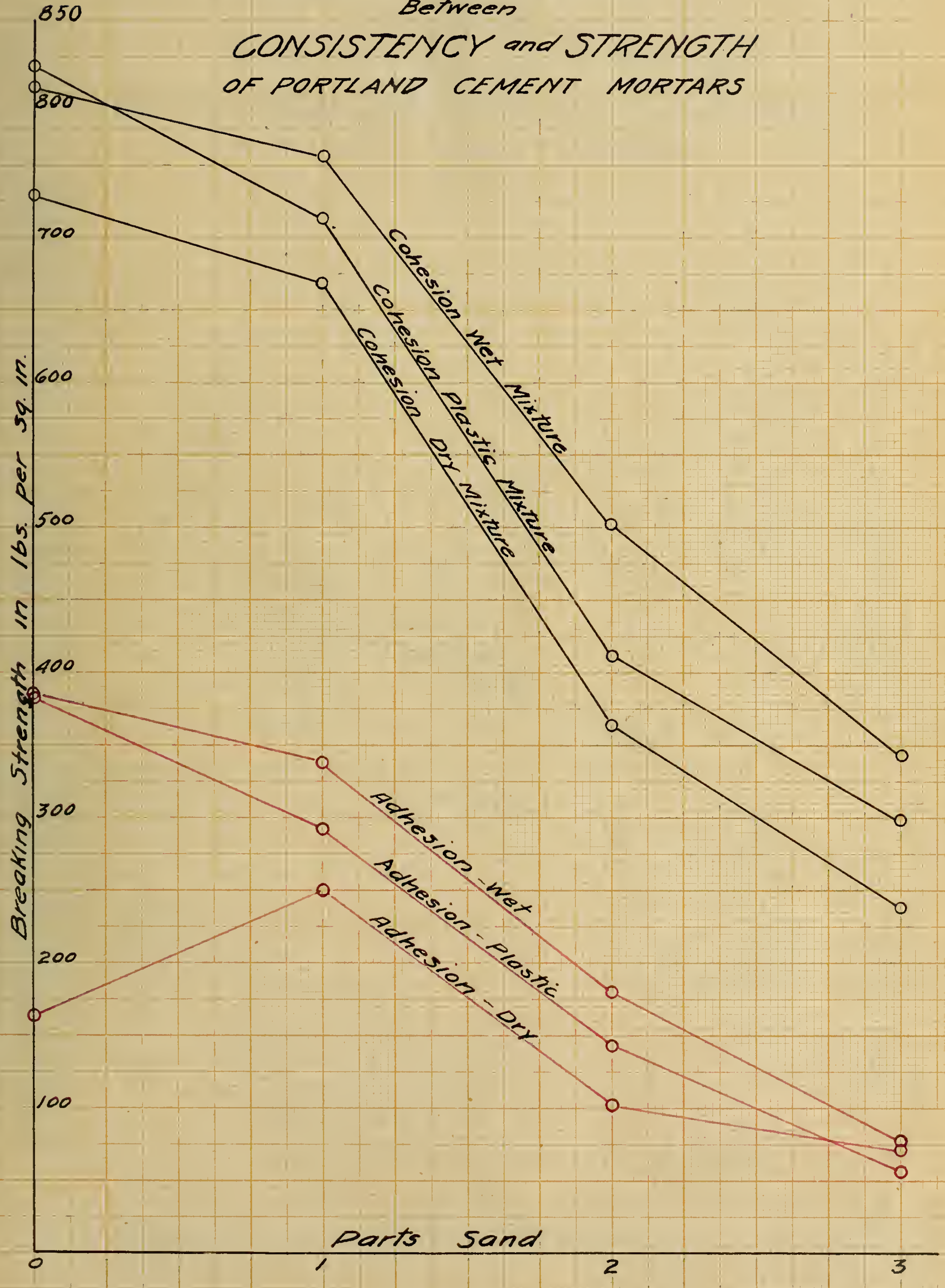


PLATE VI

CURVES SHOWING RELATION Between CONSISTENCY and RATIO of ADHESIVE to COHESIVE STRENGTH OF PORTLAND CEMENT MORTARS

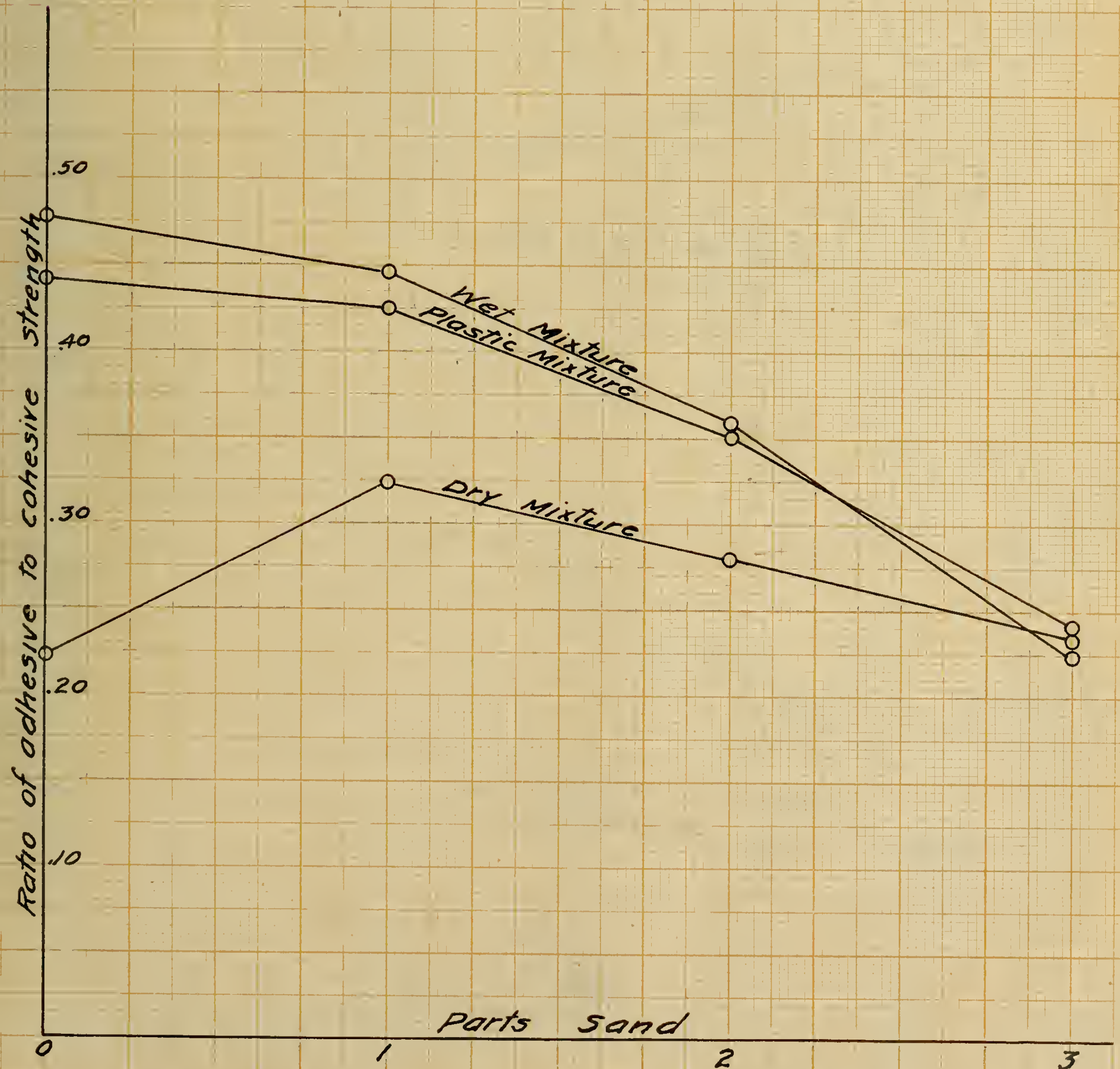


PLATE VII

CURVES SHOWING RELATION Between CONSISTENCY and STRENGTH OF NATURAL CEMENT MORTARS

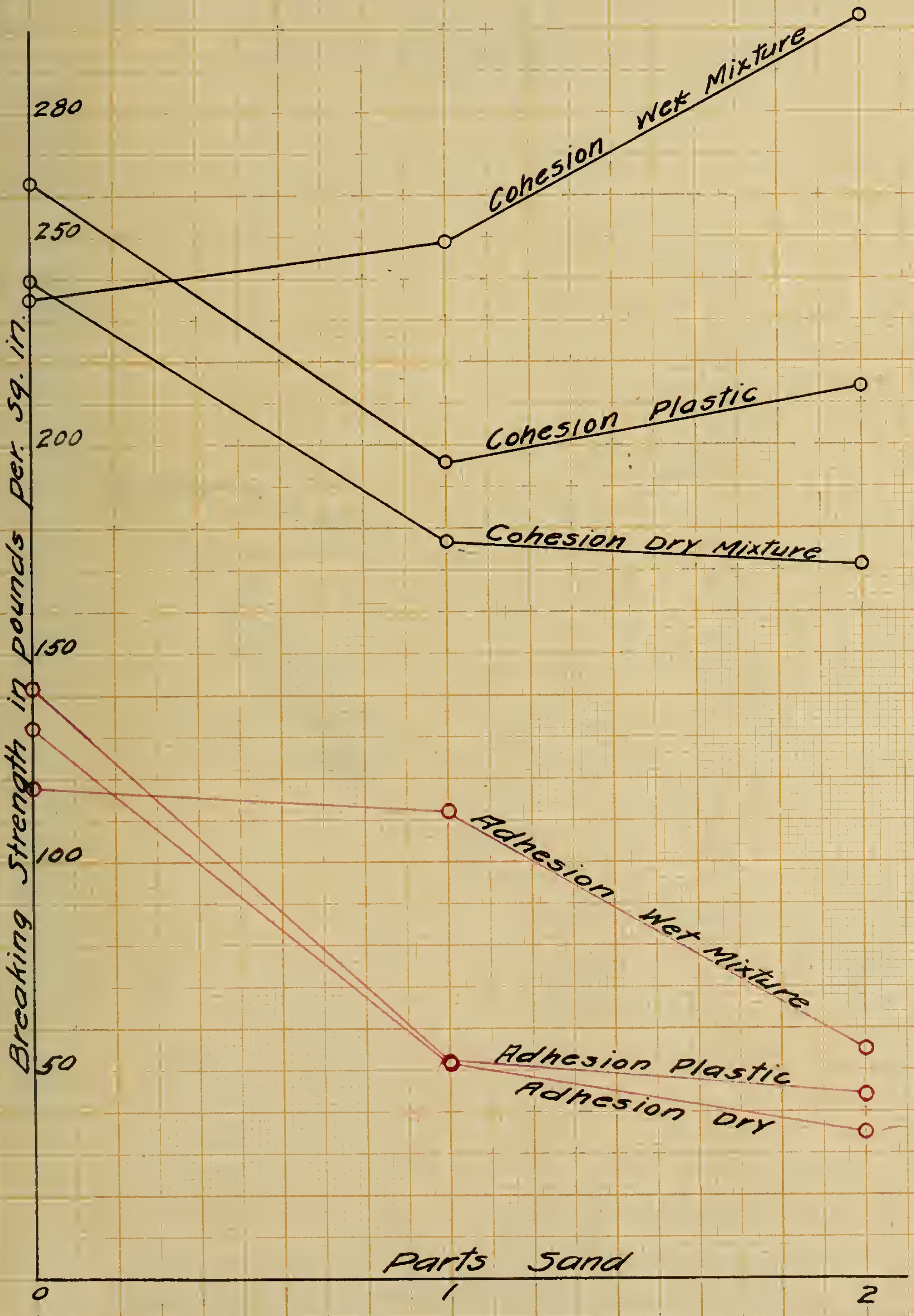


PLATE VIII

CURVES SHOWING RELATION
Between
CONSISTENCY
and
RATIO of ADHESIVE to COHESIVE STRENGTH
OF NATURAL CEMENT MORTARS

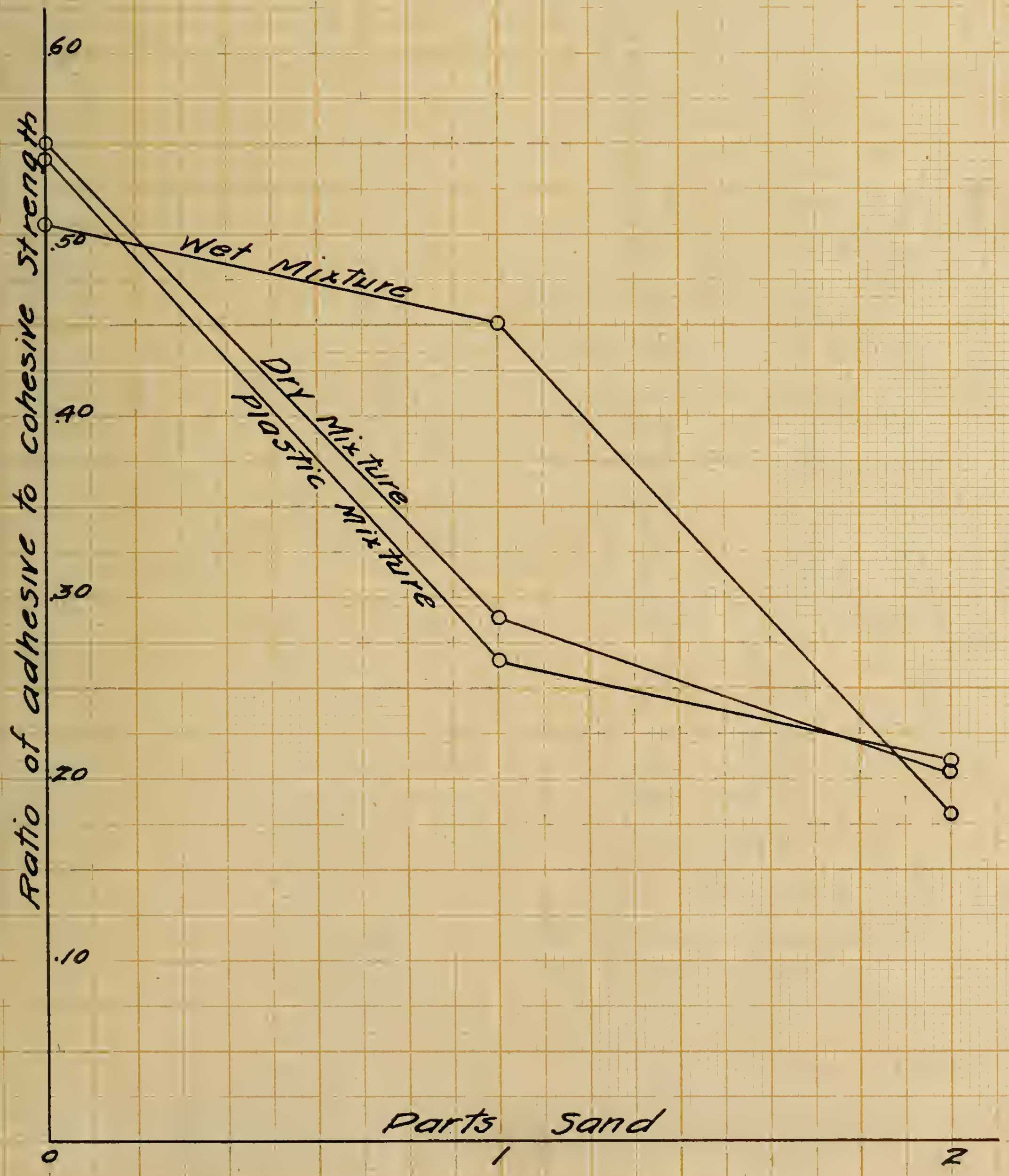


PLATE IX

CURVES SHOWING RELATION Between FINENESS of CEMENT and STRENGTH OF PORTLAND CEMENT MORTARS